Drone Swarms

A Monograph

by

MAJ Andrew William Sanders
US Army

School of Advanced Military Studies
United States Army Command and General Staff College
Fort Leavenworth, Kansas

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14. ABSTRACT

Drone swarms are here. The United States, China, and Russia are on the forefront of drone swarm development and utilization. However, the low cost and easy accessibility to drones allow non-state actors to utilize drones in imaginative and creative ways, to include swarming. The aim of the monograph is to address the following question: What utility do drone swarms provide the military? Drone swarms provide numerous advantages, to include persistent intelligence, surveillance, reconnaissance, and targeting; low-risk and low-cost to military personnel and organizations, and the potential to paralyze personal and organizational decision making. In contrast, drone swarms come with vulnerabilities and challenges. The vulnerabilities range from an adversary hacking to the existence of counter swarm weapons, and some challenges include organizational resistance and international law. Drone swarms are here and are coming to a battlefield soon, and it is time to address how best to employ them. After outlining the potential benefits and limitations of drone swarms, the monograph concludes with four recommendations: the need for narrative, establishing a drone swarm doctrine, understanding human-drone interface, and an organizational transition for drone swarm employment.

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Approved by:

_____, Monograph Director
G. Scott Gorman, PhD

_____, Seminar Leader
Todd Puntney, LtCol

_____, Director, School of Advanced Military Studies
James C. Markert, COL

Accepted this 25th day of May 2017 by:

_____, Director, Graduate Degree Programs
Prisco R. Hernandez, PhD

Abstract

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Drone swarms are here. The United States, China, and Russia are on the forefront of drone swarm development and utilization. However, the low cost and easy accessibility to drones allow non-state actors to utilize drones in imaginative and creative ways, to include swarming. The aim of the monograph is to address the following question: What utility do drone swarms provide the military? Drone swarms provide numerous advantages, to include persistent intelligence, surveillance, reconnaissance, and targeting; low-risk and low-cost to military personnel and organizations, and the potential to paralyze personal and organizational decision making. In contrast, drone swarms come with vulnerabilities and challenges. The vulnerabilities range from an adversary hacking to the existence of counter swarm weapons, and some challenges include organizational resistance and international law. Drone swarms are here and are coming to a battlefield soon, and it is time to address how best to employ them. After outlining the potential benefits and limitations of drone swarms, the monograph concludes with four recommendations: the need for narrative, establishing a drone swarm doctrine, understanding human-drone interface, and an organizational transition for drone swarm employment.

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Acronyms

ARL	US Army Research Laboratory
ARSENL	Advanced Robotic Systems Engineering Laboratory
DARPA	Defense Advanced Research Project's Agency
DOD	US Department of Defense
ISIS	Islamic State
ISR	Intelligence, Surveillance, and Reconnaissance
JP	Joint Publication
LaWS	Laser Weapon System
LOCUST	Low-Cost Unmanned Aerial Vehicle Swarming Technology
MTOE	Modified table of organization and equipment
NPS	US Naval Postgraduate School
OFFSET	Offensive Swarm-Enabled Tactics
OODA	Orient, Observe, Decide, Act
PLA	Chinese People's Liberation Army
RMA	Revolution in Military Affairs
SCO	Strategic Capabilities Office
UAV	Unmanned Aerial Vehicles
UGV	Unmanned Ground Vehicles
USV	Unmanned Surface
UUV	Unmanned Undersea Vehicle

Introduction

> In appearance the locusts were like horses prepared for battle: on their heads were what looked like crowns of gold; their faces were like human faces, their hair like women's hair, and their teeth like lions' teeth; they had breastplates like breastplates of iron, and the noise of their wings was like the noise of many chariots with horses rushing into battle.
>
> —Revelations 9:7-10, *English Standard Bible*

In July 2014, the Russians used numerous drones to conduct persistent observation on two Ukrainian mechanized battalions, allowing the Russians to mass long-range artillery to render both Ukrainian battalions combat ineffective in only three minutes.[1] In March 2015, the Defense Advanced Research Project's Agency (DARPA) announced the development of a "system-of-systems" approach that utilizes numerous low cost drones to swarm and destroy the enemy.[2] In August 2015, the Advanced Robotic Systems Engineering Laboratory (ARSENL) successfully launched a swarm of fifty drones controlled by one operator.[3] In October 2016, the US Department of Defense launched 103 autonomous drones that formed a swarm capable of decision-making, adaptation, and self-healing.[4] The US Navy has tested Low-Cost Unmanned Aerial Vehicle Technology (LOCUST) capable of launching thirty autonomous drones preprogrammed to communicate with each other and "assault the adversary with a cloud of cheap and disposable drones and paralyze defenses by sheer quantity."[5] The US Marine Corps, US Air Force, and US Army all have similar programs.

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[1] Phillip Karber and Joshua Thibeault, "Russia's New Generation Warfare," *The Potomac Foundation*, May, 2016, accessed August 27, 2016, http://www.thepotomacfoundation.org/russias-new-generation-warfare-2/.

[2] Carl Engelking, "DAPRPA's Plan to Overwhelm Enemies with Swarming Drones," *Discover Magazine*, April 6, 2015, accessed September 14, 2016, http://blogs.discovermagazine.com/drone360/2015/04/06/darpas-swarming-drones/#.V9nEwMLr2mS.

[3] Rollin Bishop, "Record-Breaking Drone Swarm Sees 50 UAVs Controlled by a Single Person," *Popular Mechanics*, September 16, 2015, accessed August 27, 2016, http://www.popularmechanics.com/flight/drones/news/a17371/record-breaking-drone-swarm/.

[4] Dyllan Furness, "The Sound of 103 Micro Drones Launched from an F/A-18 Will Give You Nightmares," Digital Trends, January 11, 2017, accessed March 17, 2017, http://www.digitaltrends.com/cool-tech/perdix-drone-swarm/.

[5] Franz-Stefan Gady, "Drone Swarms: How the U.S Navy Plans to Fight Wars in 2016," *The Diplomat*, April 23, 2015, accessed August 27, 2016, http://thediplomat.com/2015/04/drone-swarms-how-the-us-navy-plans-to-fight-wars-in-2016/.

This monograph examines the advantages and limitations of drone swarms and provides an answer to their military utility. Drone swarms allow for persistent and ubiquitous intelligence, surveillance, reconnaissance (ISR) and targeting capabilities. Aerial drone swarms can fly or loiter for hours over various locations observing target rich environments, and seaborne drones can float or submerge constantly, observing stationary or moving targets on land, at sea, or in the air. Additionally, drone swarms enhance persistent observation by "calling in" or sending data points to conduct indirect fire. Also, drone swarms allay the increasing sensitivity of leaders to casualties and reduce the monetary cost of conducting military operations. Another potential benefit of drone swarming is the effect they have on the human psyche. Ideally, the ability of drone swarms to mass with such speed and efficiency overwhelms the enemy, leaving him incapable of decision making. Conversely, drone swarms have significant vulnerabilities and challenges, including electronic and cyber threats (hacking), legal and ethical constraints, organizational limitations, and cultural resistance.

The monograph is organized into four chapters. Chapter One offers a brief synopsis of swarming and drones and provides lessons that serve as a framework for understanding drone swarms. Chapter Two examines current drone swarm capabilities and programs on air, land, and sea. The monograph continues with Chapter Three, which offers analysis on the advantages, vulnerabilities, and challenges of drone swarms and concludes with Chapter Four, recommendations for effective drone swarm employment.

Chapter 1: A Natural Phenomenon and Drones

A brief history of drones and swarming provides a framework for understanding and thinking about drone swarms. Swarming is a natural phenomenon that provides insights on the advantages and vulnerabilities of technological swarming. As an example, the army ant has mastered the advantages of swarming to conduct "massive predatory raids against other insects." [6] In fact, the success of army ant swarms has earned comparison to the notorious human marauders, the Huns and Tartars.[7] In *Swarming on the Battlefield: Past, Present, and Future*, Sean J.A. Edwards assesses the feasibility of integrating swarm tactics into US military doctrine and claims the Mongols were the "ultimate swarmers," the exemplars of swarming at the tactical and operational level.[8] Like swarming, unmanned weapon systems have been used for thousands of years.[9] Thucydides in *The Peloponnesian War* writes of the Spartan's filling old ships with wood and kindle, lighting the ships on fire ("fireships") and sending them down stream towards the Athenian navy.[10] In 333 BC the Tyrians could not afford to jeopardize the loss of manpower to break Alexander the Great's siege at the port of Tyre, so they used "fireships" instead.[11]

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[6] T.C. Schneirla, *Army Ants: A Study in Social Organization* (San Francisco: W.H. Freeman and Company, 1971), 1; see Bines.

[7] William H. Gotweld Jr., *Army Ants: The Biology of Social Predation* (Ithaca, NY: Cornell University Press, 1995), 6.

[8] Sean Edwards, *Swarming on the Battlefield: Pat, Present, and Future* (Washington, DC: RAND, 2000), iii.

[9] Scott Savitz, et al., *US Navy Employment Options for Unmanned Surface Vehicles (USVs)* (Santa Monica: RAND, 2013), 1.

[10] Thucydides, "The Seventh Book," in *The History of the Peloponnesian War*, trans. Richard Crawley (n.p.: The Internet Classic Archives, 431), under "7.53.4," accessed April 23, 2017, http://classics.mit.edu/Thucydides/pelopwar.7.seventh.html.

[11] Marc G. De Santis, "Alexander the Great and the Siege of Tyre," Warfare History Network, December 29, 2015, accessed December 3, 2016, http://warfarehistorynetwork.com/daily/military-history/alexander-the-great-and-the-siege-of-tyre/.

Swarming, defined by *Merriam Webster Dictionary* as “a large number of animate or inanimate things massed together and usually in motion,” provides a method that combines situational awareness, elusiveness, mass, speed, mobility, and surprise to physically and cognitively overwhelm prey.[12] Drones, as defined by *Merriam Webster Dictionary*, are “an unmanned aircraft or ship guided by remote control or onboard computers” and a means that are cheaper, less risky, and provide more flexibility, durability, and better ISR than manned vehicles.[13] However, history shows swarming is vulnerable to symbionts, restrictive terrain, and other swarms. Similarly, drones are vulnerable to electronic warfare and are available to a host of nonstate actors that are not afraid to use them. The strengths and vulnerabilities highlighted in this chapter provide lessons, fundamentals, and a framework for drone swarm utilization.

Army ant swarms move over twenty yards per hour at a width of twenty meters and length of up to 100 meters, attacking from air (trees and winged ants), land, and underground, and often catch prey by surprise.[14] Similarly, an Asian Giant Hornet swarm, traveling up to sixty miles in a day at twenty-five miles per hour, attack prey from all directions, and can destroy an entire honeybee colony (up to 30,000) in four hours.[15] In the 15th century, the Chinese used an early version of a drone by utilizing live birds in a very similar way that ants and hornets swarm and modern militaries use unmanned aerial vehicles. The Chinese strapped burning embers around the neck of the “firebirds” and released them to swarm enemy encampments or cities, in which the embers burned through the pouch dropping to the ground starting massive fires that led to destruction of camps and towns.[16] The speed, surprise, and mass of ant and

[12] "Swarm," *Merriam-Webster.com*, accessed September 14, 2016. http://www.merriam-webster.com/dictionary/swarm.

[13] "Drone," *Merriam-Webster.com*, accessed September 14, 2016, http://www.merriam-webster.com/dictionary/drone.

[14] Gotweld, *Army Ants: The Biology of Social Predation*, 120; Schneirla, *Army Ants: A Study in Social Organization*, 84.

[15] Dieter Kosmeier, "*Vespa Mandarinia* (Asian Giant Hornet),” January 27, 2013, accessed December 13, 2016, http://www.vespa-crabro.de/vespa-mandarinia.htm.

[16] Joseph Needham et al., *Science and Civilization in China*, ed. Joseph Needham, vol. 5, *Chemistry and Chemical Technology, Military Technology: The Gunpowder Epic 7* (Cambridge: Cambridge University Press, 1987), 1.

hornet swarms shock and paralyze prey, leaving little time to react.[17] Similarly, the Chinese use of "firebirds" to surprise and shock the enemy decreased risk to friendly archers, who usually had to move within close proximity to the enemy to gain the same effects.

The "firebird" provided low risk to their operators and shock to the enemy, but "firebirds" often flew back into friendly encampments causing havoc and the same effects intended for the enemy. Similarly, ant and hornet swarms are vulnerable to symbionts or natural hackers who devour their host, and other swarms that bait their enemy into destruction.[18] Ant symbionts (e.g. beetles and snakes) are allowed to travel with or in an ant swarm unharmed, but after time, some symbionts turn on their host and destroy them. Drones are capable of providing a ubiquitous presence throughout the battlefield, but are also susceptible to being "hacked" and turned against friendly forces. These vulnerabilities are pertinent to military drone swarms. Hackers can insert a virus into the software of a drone swarm and hijack the swarm for their own purpose, to include destroying the drone swarm, or worse, turning the swarm on its original master.

Fish swarm to avoid predation and increase vigilance.[19] Milinski and Heller posit that by schooling in massive swarms, potential predators become confused and overwhelmed, and are unable to identify individual fish within swarms.[20] Pigeon swarms have the same effect on predator hawks. According to R.E Kenward, hawks tend to be "more confused" and "less confident in attacks on large flocks…" than on smaller flocks or individual pigeons, and therefore less successful.[21] Another benefit of

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[17] Gotweld, *Army Ants: The Biology of Social Predation*, 133; Kosmeiier, "*Vespa Mandarinia* (Asian Giant Hornet)."

[18] Schneirla, 85 and 93; Piper, Ross, *Extraordinary Animals: An Encyclopedia of Curious and Unusual Animals* (Westport: Greenwood Press, 2007), 9–11; Michio Sugahara and Fumio Sakamoto, "Heat and Carbon Dioxide Generated by Honeybees Jointly Act to Kill Hornets," *Naturwissenschaften* 96, no. 9 (September 1, 2009): 1133-36.

[19] Milinski Manfred and Rolf Heller, "Influence of a Predator on the Optimal Foraging Behavior of Sticklebacks," *Nature* 275 (October 19, 1978): 642-44.

[20] Milinski and Heller, 642-644.

[21] R. E. Kenward, "Hawks and Doves: Factors Affecting Success and selection in Goshawk Attacks on Woodpigeons," *Journal of Animal Ecology*, Vol. 47, No. 2 (Jun., 1978), p 449-460

fish swarms is the large quantity of fish increases and broadens vigilance.[22] The fish and pigeon swarms provide a persistent and broadened situational understanding of the environment, while confusing predators. Swarms provide safety in numbers for fish and pigeons on the defensive; however, for drone swarms safety in numbers allows the swarm to lose a few drones and still overwhelm enemy defenses.

The Mongols and Napoleon used similar swarming techniques as ants, fish, and birds and with similar results. Edwards attributes the Mongol mastery of situational awareness, mobility, intelligence, and "stand-off" fire as criteria for successful swarming.[23] The Mongol swarm consisted of several divisions with a front that stretched up to 600 miles. Upon identification of the enemy the closest Mongol divisions pounced on the enemy from various directions, with the first division to make contact fixing or delaying the enemy while the other divisions proceeded with encirclement.[24] With mounted carriers and other means, Mongol communication enhanced situational awareness and mobility, feeding a swarm that the enemy never saw coming, first inflicting mental and physical paralysis, proceeding with encirclement, and ending with annihilation.[25] By the time the enemy had a grasp of what was happening, it was too late. The Mongol horde was gone as quickly as it came, leaving the remnants of an annihilated enemy behind to ponder what had happened.

At Ulm, Napoleon used swarming nearly flawlessly. Napoleon used individual corps to separately move towards the battle, only to converge and swarm the enemy at the right time. The operation required surprise, timely maneuver, and mass with little communication between the corps; drone swarms are capable of the same, but with less risk to human life, less monetary cost to military organizations, and greater stand-off. Further, David Chandler writes that General Mack, Napoleon's opposing general, was "hypnotized" to the whereabouts of Napoleon's army, and even upon recognition of what was unfolding

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[22] Gilbert Roberts, "Why Individual Vigilance Declines as Group Size Increases," *Animal Behavior* 51 (1996): 1077-86.

[23] Roberts, "Why Individual Vigilance Declines as Group Size Increases," 1077-86.

[24] Edwards, *Swarming on the Battlefield: Pat, Present, and Future*, 29.

[25] Ibid, 30.

around him, "the rabbit remained hypnotized by the snake."[26] Mack remained so paralyzed to what was happening that he actually believed Napoleon's army had retreated, when in fact Napoleon had swarmed and encircled Mack's entire 72,000-man army. It was hardly a fight; the speed and power of Napoleon's swarm and encirclement was shouted as a masterpiece and "never have victories been so complete and less costly."[27] It was a tactical and operational success; however, the psychological effect Napoleon's swarm had on his enemy is most germane. Chandler continues that Mack was strategically defeated in large part to "the demoralization consequent upon discovering a powerful enemy on his rear had played a decisive point in paralyzing his victim…"[28] Napoleon's swarm had been such a surprise and novelty to Mack that his senses were unable to process what was unfolding. Mack could not make a decision. Novelty combined with speed, mass, and elusiveness are attributes enhanced by drone swarms, and much like Napoleon's Great Army at Ulm, provide operational shock and cognitive dissonance to opposing military systems and personnel.

In *Swarming and the Future of Warfare*, John A. Arquilla and David Ronfeldt compare natural swarming to the "guerilla" style warfare of the North Vietnamese and Viet Cong.[29] In Vietnam, the North Vietnamese and Viet Cong hit American forces with surprise attacks from all directions, appearing "omnipresent," and disappearing back into the countryside.[30] The omnipresence of swarming is heightened by drones. For example, the Israelis have the Hermes 1500, a mammoth UAV that acts as a mobile communications hub and relay system, and in turn expands communication, observation, and ISR capabilities.[31] An even larger unmanned aerial vehicle (UAV), the TP Titan, functions as an ISR platform and can loiter for up to thirty-six hours. Further, the Israelis have designed and used a small rotary-wing

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[26] David G. Chandler, *Campaigns of Napoleon* (New York: Scribner, 1966), 394.

[27] Chandler, *Campaigns of Napoleon,* 394.

[28] Ibid, 402.

[29] Arquilla and Ronnfeldt, 25-27.

[30] Public Broadcast System, "Battlefield: Vietnam/Guerilla Tactics," April 20, 2017, accessed April 20, 2017, http://www.pbs.org/battlefieldvietnam/guerrilla/index.html.

[31] Paul J. Springer, *Military Robots and Drones* (Santa Barbara, CA: ABC-CLIO, 2013), 100.

ISR platform that loiters over a target for three hours.[32] Also, the Israeli's are experimenting with drone balloons and aerostats that can loiter and provide overwatch, surveillance, and target acquisition indefinitely.[33] Combining Vietnamese swarming methods with the Israeli Hermes and Titan drones, drone swarms are capable of indefinite omnipresence for persistent ISR and targeting, and if necessary immediate dispersion.

In the 13th century work, *The Book of Military Horsemanship and Ingenious War Devices*, Hasan al-Rammah describes the first torpedo.[34] The unmanned "fireships" were used for thousands of years; however, the ships were expensive and difficult to maneuver and aim. The torpedo was much more effective and cheaper than the "fireship," in that many torpedoes could be launched at once, increasing the likelihood of hitting the target and adding multiple dilemmas to the enemy, cheaper and cost less than "fireships." Today, militaries are searching for the same effects in targets and fiscal efficiency. For example, in 2014, the Navy conducted a successful unmanned vessel swarm test controlled by just one sailor.

Swarming and drones are a method and means with advantages; however, adversaries adapt. For example, against the Scythians, Alexander used similar anti-swarm methods that bottlenose dolphins use to catch swarming fish. In order to catch fish utilizing swarms ("bait balls"), bottlenose dolphins pin the swarm against the surface or other obstacles that prevent escape, forcing individual fish to leak from the swarm and thus become prey. Edwards writes that Alexander preferred a similar method against the Scythians and "realized that the best way to come to grips…was to pin the swarmer against an obstacle, such as a river or a fort."[35] Drone swarms, specifically, unmanned surface and undersea vehicles (USV and UUV) swarms can be pinned against an array of obstacles.

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[32] Springer, *Military Robots and Drones*, 101.

[33] Ibid.

[34] Hasan Al-Rammah, *The Book of Military Horsemanship and Ingenious War Devices*, ed. Ahmad Al-Hassan (Aleppo: University of Aleppo, 1998), 1.

[35] Edwards, *Swarming on the Battlefield: Pat, Present, and Future*, 16.

Unmanned aerial drones have provided Israel superior situational understanding and targeting over their enemy since 1982; the United States has used the Predator to observe, target, and kill adversaries since 2001, instilling psychological and physical shock to the enemy system.[36] But, adversaries have adapted. Terrorist groups like Hezbollah, Hamas, and the Islamic State (ISIS) all have used unmanned aerial or ground vehicles. In 2014, Fars News Agency reported that Hezbollah achieved its first drone strike, killing around twenty-three Syrian rebels.[37] ISIS is known to have used both off the shelf UAVs to conduct reconnaissance and unmanned vehicles to conduct bombings.[38] Unmanned marine vehicles, especially subsurface, are harder to control and are more expensive, and therefore, harder for non-state actors to attain.[39] However, cheap surface vehicles are readily available.

Swarming is not new, and neither are drones. Swarming is a billion-year natural phenomenon and human beings have used unmanned weapons and vehicles for thousands of years. Swarming and drones each have distinct but similar advantages and vulnerabilities. Combined, the advantages of swarming and drones are enhanced, and so are the vulnerabilities. Modern swarming offers an intriguing continuity to the historical precedence of swarming and drones.

[36] Springer, *Military Robots and Drones*, 182.

[37] Chris Abbot, et al., "Hostile Drones: The Hostile Use of Drones by Non-State Actors Against British Targets," *The Remote Control Project*, January 2016 (London: Remote Control Project, 2016), 8.

[38] Ibid, 10.

[39] Ibid, 8.

Chapter 2: Drone Swarms

Militaries around the world have recognized the effectiveness of both swarming and drones, and now understand the potential of drone swarms. The United States, China, and Russia are the most prominent, but countries like Iran and non-state actors such as the Islamic State pursue drone swarming. This chapter provides examples of current drone swarm utilization, and is broken down into three sections: aerial drone swarms, ground drone swarms, and maritime drone swarms.

Aerial Drone Swarms

On August 27, 2015, the US Naval Postgraduate School (NPS) Advanced Robotic Systems Engineering Laboratory flew fifty autonomous UAVs. The UAVs were launched in two "subswarms" of twenty-five drones each in which the drones made limited decisions on their own using interfaces and only two human operators.[40] In June 2016, the US Navy's Office of Naval Research tested a swarm of thirty-one drones, tube launched in forty seconds, and proceeded to conduct swarm maneuvers with minimal human direction.[41] Meanwhile, the US Air Force is working on the development of micro-drone swarms. Micro drones are relatively cheap and allow large drone swarms to overwhelm enemy radar and air defenses, providing too many targets at once and yet small enough to avoid detection.[42] The US Air Force is not trying to eliminate the need for manned flight; however, drones can enhance human pilot capabilities. For example, the US Air Force seeks to balance human and autonomous interaction by allowing human pilots to control groups of drones during missions.[43] The US Army looks to use micro-

[40] Lewis Hunsaker, "ARSENL Reaches Its Ultimate Goal of 50 Autonomous UAVs in Flight," Naval Postgraduate School Public Affairs, August 31, 2015, accessed December 19, 2016, http://www.navy.mil/submit/display.asp?story_id=90863.

[41] Hope Hodge Seck, "Navy to Demo Swarming Drones at Sea in July," Miitary.com, June 24, 2016, accessed December 19, 2016, http://www.military.com/daily-news/2016/06/24/navy-to-demo-swarming-drones-at-sea-in-july.html.

[42] Kris Osborn, "Pentagon's Plan to Overwhelm Russian and Chinese Air Defenses," *The National Interest*, May 10, 2016, accessed December 20, 2016, http://nationalinterest.org/blog/the-buzz/swarming-mini-drones-inside-the-pentagons-plan-overwhelm-16135.

[43] United States Air Force, Office of the Chief Scientist, "Autonomous Horizons" (Washington, DC: US Air Force, 2015), 14.

drone swarms for ISR missions by 2020 and ubiquitous sensors by 2025.[44] Also, the US Army, much like the US Air Force, plans to use micro-drone swarms to provide force projection to ground forces.[45] In January of 2017, the Pentagon announced the successful launch of 103 six-inch micro drones capable of "advanced swarm behaviors such as collective decision-making, adaptive formation flying and self-healing."[46] William Roper, director of the Pentagon's Strategic Capabilities Office (SCO) says the swarm is a "collective organism, sharing one distributed brain…adapting to each other like swarms in nature."[47] The goal of the SCO is to launch a drone swarm of up to 1,000 drones. The United States also recognizes the potential impact of enemy drone swarms. US Army LTG H.R. McMaster acknowledges the importance of countering the "low, slow, small" drones that proved so effective for the Russians in the Ukraine.[48]

Similar to the US Air Force, by 2025 Russia expects to debut a "sixth-generation" fighter jet with supersonic speed and five to ten unmanned drones at its side that can leave the atmosphere and reenter at a different point traveling at Mach four to five.[49] Russia is currently using multiple drones to enhance ISR and targeting. In June 2016, Swedish and Norwegian military forces claimed observing drones loitering over NATO military exercises. In some incidents, there were up to ten drones close together hovering and behaving in a manner indicative of observation.[50] Many in the Swedish and Norwegian governments

[44] Patrick Tucker, "US Army Racing to Catch Up to Russia On Battle Drones," *Defense One*, September 28, 2016, accessed December 30, 2016, http://www.defenseone.com/technology/2016/09/us-army-racing-catch-russia-battle-drones/131936/.

[45] Ibid.

[46] Phys.org, "Pentagon Successfully Tests Micro-Drone Swarm," *Phys.org*, January 10, 2017, accessed January 10, 2017, https://m.phys.org/news/2017-01-pentagon-successfully-micro-drone-swarm.html

[47] Ibid.

[48] Tucker, "US Army Racing to Catch Up to Russia On Battle Drones."

[49] Brendan McGarry, "Russia Touts Drone Swarms and Electromagnetic Cannon for Sixth-GenFighter," *Defensetech*, July 13, 2016, accessed December 20, 2016, http://www.defensetech.org/2016/07/13/russia-touts-drone-swarms-and-electromagnetic-cannon-for-sixth-gen-fighter/.

[50] Shehab Khan, "Unidentified Drones Spotted Above Nordic Military Exercise," *The Independent*, last modified December 11, 2016, accessed December 13, 2016, http://www.independent.co.uk/news/world/europe/unidentified-drones-spotted-nordic-military-exercises-russia-sweden-norway-a7468251.

believe the source of the swarm to be Russian.[51] Further, the Russians maintain air dominance in eastern Ukraine in large part thanks to multiple drones.

China is moving forward and fast with aerial drone swarms. China announced the successful launch of a sixty-seven drone swarm and currently makes a kamikaze drone with explosive warheads.[52] The People's Liberation Army (PLA) of China has one of the largest and most organized UAV programs in the world and plans on using a significant amount of these drones to swarm US aircraft carriers.[53] According to Easton and Hsiao, the Chinese plan to use drone swarms against aircraft carriers with decoys, electronic warfare UAVs and anti-radiation drones, armed UAVs, and communications relay UAVs.[54] The decoy UAVs act to trick US pilots and ship defenders into exhausting missile stocks. Following decoy drones, a swarm of electronic warfare, anti-radiation, and armed drones are deployed to jam communication and radar systems, attack early warning radar, and fly as kamikazes into ships.[55] Additionally, the Chinese ASN-207 drone is designed primarily for ISR, but capable of target acquisition and designation, and communication relays.[56] The Chinese military uses multiple ASN-207 systems at a time, in tandem, with one drone acting as a communication relay, and which according to Springer, allows for a "massive expansion of systems range—of several hundred kilometers—and becomes a formidable platform that can loiter indefinitely while maintaining a secure data link for real-time updates."[57]

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[51] Khan, "Unidentified Drones Spotted Above Nordic Military Exercise."

[52] Davis Hambling, "If Drone Swarms Are the Future, China May Be Winning," *Popular Mechanic*s, December 23, 2016, accessed January 26, 2017, http://www.popularmechanics.com/military/research/a24494/chinese-drones-swarms/.

[53] Ian Easton and Russell Hsiao, *The Chinese People's Liberation Army's Unmanned Aerial Vehicle Project: Organizational Capacities and Operational Capabilities* (Arlington, VA: Project 2049, 2013), 11-14.

[54] Ibid.

[55] Ibid.

[56] Jeremy Hsu, "China's Drone Swarms Rise to Challenge US Power," *LiveScience.com*, last modified March 13, 2013, accessed December 13, 2016, www.yahoo.com/news/chinas-drone-swarms-rise-challenge-us-power-173949154.html?ref=gs.

[57] Springer, *Military Robots and Drones*, 85.

Aerial drone swarm technology does not exclusively belong to state actors. Non-state actors like Hezbollah, Hamas and ISIS are pursuing the use of drone swarms for purposes of attack and ISR. In 2006, Hezbollah launched three small drones with explosive payloads to attack Israeli military targets, but were shot down by the Israeli air force.[58] In 2014, Hamas claims to have flown three armed drones over Israeli airspace (although Israel claims only one drone, which it shot down).[59] Recent reports suggest ISIS has used drone swarms since 2014 primarily for ISR. However, as recently as early 2017, ISIS has used drones to drop grenades on Iraqi forces and civilians.[60] Although there have been no reports of multiple drones or swarms used by ISIS, there are indications that ISIS is becoming more advanced in their ability to maximize multiple drones.[61]

The US Army expects UAV swarms to be at initial operational capability (e.g. manned-unmanned teaming) within five to ten years and at full operational capability in the next ten to twenty years.[62] However, Russia and China are not far behind, and non-state actors are also keeping pace.

Ground Drone Swarms

The development of robotic and unmanned ground vehicles (UGV) swarms are here and are becoming integrated in military operations.[63] The US Army Research Laboratory (ARL) envisions fully operational UGV and robotic swarms by 2050.[64] ARL anticipates ground drone swarms to be ubiquitous, capable of observing and attacking "every inch of the battlefield," self-organized, and collaborative.[65]

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[58] Abbot, et al, "Hostile Drones: The Hostile Use of Drones by Non-State Actors Against British Targets."

[59] Ibid.

[60] Gabriel Avner, "ISIS is Using DJI Phantom Drones to Drop Bombs Over Mosul," *Geektime*, January 15, 2017, http://www.geektime.com/2017/01/15/isis-is-using-dji-phantom-drones-to-drop-bombs-over-mosul/.

[61] According to Avner, ISIS is using attack drones at least once a day.

[62] US Army, *The U.S Army Robotic and Autonomous Systems Strategy* (Fort Eustis: TRADOC, 2017), 7-10.

[63] John Antal, "The Next Wave: Racing Toward Robotic War," *Military Technology*, May 2016, 84.

[64] Alexander Kott et al., *Visualizing the Tactical Ground Battlefield in the Year 2050: Workshop Report* (Adelphi, MD: US Army Research Laboratory, 2015), 16-17.

[65] Ibid.

Additionally, robots and drone swarms do not need sleep or food, and are not distracted or limited by bias, emotions, experience, and physical limitations.[66] Further, the ARL envisions collaborative swarms of humans and robots.[67] DARPA recognizes the potential and is developing a program to enhance the interface between humans and robots.[68] Robotic ground swarms are coming, but still are a few years away; UGV swarms, however, provide a plausible and near-term alternative.

As of May 2016, the US Army has more than 12,000 UGVs in operation.[69] Further, the Army plans on using UGV for drone swarms. The US Army prefers to use UGV swarms for support operations, to include autonomous or near autonomous logistical convoys, "mules" to carry equipment and supplies for infantry soldiers, and scout missions.[70] However, the US Army continues to test and develop remote controlled attack vehicles capable of swarming ahead of or with human soldiers.[71] The Navy and Marines are becoming the vanguard in ground drone swarms. Robert Work, former Navy Under Secretary and Deputy Secretary of Defense, calls for the development of autonomous "reconnaissance-strike swarms," capable of identifying and attacking the enemy.[72] Work envisions robotic killer bees or ants, with bombs and bullets instead of stingers, and Wi-Fi in place of pheromones.[73] The US Marines hope to take advantage of the mass drone swarms provide. Deputy Commandant of the Marine Corps, Lt. Gen. Robert Walsh sees "swarm-type technology" as a dominant method of warfare, cheaper, and optimal for

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[66] Antal, "The Next Wave: Racing Toward Robotic War," 84.

[67] Kott, et al., "Visualizing the Tactical Ground Battlefield in the Year 2050: Workshop Report," 17.

[68] Mariana Iriarte, "DARPA Plans to Develop Unmanned Swarm Tactics," *Military Embedded Systems*, December 9, 2016, accessed January 17, 2017, http://mil-embedded.com/news/developing-swarm-tactics-is-main-goal-of-new-darpa-offset-program/.

[69] See Antal, "The Next Wave: Racing Toward Robotic War," 84.

[70] Sydney J. Freedberg, "Bird Dogs & Drones, Terminators & Swarms: The Race Towards Robotic Warfare," *Breaking Defense*, January 23, 2014, accessed on January 24, 2017, http://breakingdefense.com/2014/01/bird-dogs-drones-terminators-swarms-the-race-towards-robotic-warfare/.

[71] Sydney J. Freedberg, "Robot Shoots 'Em up: Army Assesses Northrop's MADSS," *Breaking Defense*, October 8, 2013, accessed January 24, 2017, http://breakingdefense.com/2013/10/robot-shoot-em-up-army-assesses-armed-bot-madds/.

[72] Freedberg, "Bird Dogs & Drones, "Terminators & Swarms: The Race Towards Robotic Warfare."

[73] Ibid.

leveraging mass.[74] Walsh sees ground drone swarms that are launched ahead of the main body that can detect "enemy transmissions, triangulate their locations, and then attack by themselves or pass targeting data back to heavier weapons." These types of swarms are not theoretical; the Army, Navy, and Marines are adapting UGVs and robots already in the inventory and developing future models for ground drone swarms, refining the best methods for operations. However, the Army does not anticipate fully autonomous platforms until 2035, and fully autonomous swarms until 2050. In contrast, the Navy and Marines think rudimentary ground swarms can operate now and more autonomous ground swarms in the near future.[75]

John Antal states in his article, "The Next Wave: Racing Toward Robotic War," that Russia claims to have Strategic Missile Force bases guarded by a swarm of "armed, shoot-to-kill, remotely controlled mobile sentry robots."[76] Similarly, Antal notes in 2015, Russia announced the completion of a UGV with the capacity to fire a machine gun, cannon, anti-tank missiles, and surface-to-air missiles.[77] Further, Antal highlights Russia's desire to enlarge their ground swarms by developing entire units "capable of independently conducting military operations."[78]

China has developed the SHARP CLAW 2, a robotic armored reconnaissance vehicle capable of autonomous operations and the capacity to act as a "mothership" with other drones stored inside or attached to the vehicle.[79] For example, the SHARP Claw 2 is capable of carrying and deploying an aerial quadcopter and a smaller attack UGV.[80] Also, China has autonomous or remote-controlled vehicles

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[74] Sydney J. Freedberg, "Marines Seek to Outnumber Enemies with Robots," Breaking Defense, October 25, 2016, accessed January 24, 2017, http://breakingdefense.com/2016/10/marines-seek-to-outnumber-enemies-with-robots/.

[75] Ibid.

[76] Antal, "The Next Wave: Racing Toward Robotic War," 84.

[77] Ibid.

[78] Antal, "The Next Wave: Racing Toward Robotic War," 84.

[79] Ibid.

[80] Jeffrey Lin and P.W. Singer, "China's New Military Robots Pack More Robots Inside (Starcraft-Style)," *Popular Science*, November 11, 2014, accessed January 26, 2017, http://www.popsci.com/blog-network/eastern-arsenal/chinas-new-military-robots-pack-more-robots-inside-starcraft-style.

capable of providing a swarm of medical, logistical, and transportation aid.[81] According to Antal, like DARPA, the Chinese PLA "is also working on a man-machine brain interface" and already training students to use "brain computer interfacing…to control robots."[82]

Rebels in Libya fighting the Ghaddafi regime in 2011 used remoted controlled toys mounted with machine guns. Al Sunnah has used similar vehicles in Syria, and the Free Syrian Army used a remote controlled mini tank against Assad forces in 2013. There is no evidence, however, that non-state actors have developed or used ground UGV in groups of swarms.[83] The advanced technology required for ground swarms and the difficulty that terrain presents UGVs appear to have precluded advancement of UGV swarms by non-state actors. Human swarming remains the ideal method for non-state actors; however, as drones and robotic technology become cheaper and more accessible, ground swarms may become a viable option for non-state actors soon.

Unmanned ground vehicles and robotics are progressing rapidly, but not so for ground swarms. Terrain poses challenges to ground swarms that aerial swarms do not encounter. Like human swarming, natural and man-made obstacles make it difficult for UGV and robots to swarm. Further, the land domain requires a higher level of sophistication and moving parts than the air domain for successful swarming. UGV and robotic sophistication has yet to meet the requirements for ground swarming, and therefore, ground swarming will likely be the last type of swarming to emerge, behind aerial and maritime drone swarms.

[81] Lin and Singer, "China's New Military Robots Pack More Robots Inside (Starcraft-Style)."

[82] Antal, "The Next Wave: Racing Toward Robotic War," 84.

[83] Robert Bunker and Alma Keshavarz, *Terrorists and Insurgents Teleoperate Sniper Rifles and Machine Guns* (Fort Leavenworth, KS: US Army Foreign Military Studies Office, 2016), 2-29.

Maritime Drone Swarms

The air domain is likely the first to host operational drone swarms, but maritime drone swarm development is closing the gap in favor of the sea.[84] Similar to the air domain, the sea offers unique swarm possibilities for both USV and unmanned undersea vehicles (UUV).[85] Maritime swarms offer fleet and port defense, continuous surveillance and observation on the surface and below it, mine detection, and UAV counter-measures. As with aerial and ground swarming, the United States, Russia, and China remain in the forefront of maritime drone swarms.

The Sea Mob Project is an inconspicuous US Department of Defense program designed "to develop a group of USVs capable of cooperative swarming."[86] In 2014, the US Office of Naval Research took a step towards cooperative swarming by announcing the successful test launch of unmanned autonomous boat swarms designed to protect Navy vessels and US ports.[87] The Navy argues operational boat swarms can help counter swarm assaults similar to what happened to the USS Cole.[88] In October 2016, the United States, United Kingdom and other allies participated in "Unmanned Warrior," a combined exercise focusing on naval mine-sweeping using swarms of unmanned vehicles.[89] The combined forces leveraged maritime drone technology by networking "10 different vehicles, aerial drones, robot boats, and autonomous mini-subs" to conduct autonomous mine sweeping.[90] The unmanned maritime vehicles are capable of interfacing with each other, and are capable of distinguishing between

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[84] Marty Kauchak, "Closing the Gap: Unmanned Maritime Vehicle Development," *Military Technology* (May, 2016): 93-97.

[85] Ibid, 96.

[86] Ibid.

[87] David Smalley, "The Future is Now: Navy's Autonomous Swarm Boats Can Overwhelm Adversaries," Office of Naval Research, last modified 2014, accessed January 31, 2017, https://www.onr.navy.mil/en/Media-Center/Press-Releases/2014/autonomous-swarm-boat-unmanned-caracas.aspx.

[88] Ibid.

[89] Sydney J. Freedburg Jr., "US, UK Do 'Groundbreaking' Drone Exercise Off Scotland," *Breaking Defense*, October 14, 2016, accessed January 31, 2017, http://breakingdefense.com/2016/10/us-uk-do-groundbreaking-drone-exercise-off-scotland/.

[90] Ibid.

friendly and enemy forces.[91] Upon identification of enemy vessels, the autonomous boats are capable of swarming and neutralizing the target.

The US Marines are interested in unmanned amphibious vehicles that swarm beaches transporting personnel and equipment more efficiently and with less risk than manned vehicles.[92] DARPA is testing the "Sea Hunter," a large "132-foot ship capable of travelling up to 10,000 nautical miles to hunt for submarines and underwater mines."[93] The goal is for the Sea Hunter to interact with other ships, boats, and submarines, manned and unmanned to leverage swarm techniques. The advantages of US maritime drone swarms are significant; however, they are not without problems. Communication between different types of drones pose challenges, especially with maritime drones developed in different countries. Also, experts are concerned about adversaries hacking maritime drones, shutting the drones down or worse, turning them against their maker.[94]

Russia is testing underwater drones to counter unmanned vehicles similar to the US "Sea Hunter," acting as a decoy to draw submarines out or conduct sonar jamming.[95] One underwater drone is capable of travelling up to 600 miles as deep as 600 meters below the surface. Long range reconnaissance and attack maritime drones are also in the making.[96] In November 2016, Russia tested an unmanned underwater vehicle equipped with nuclear warheads and capable of traveling 6,200 miles at a depth of

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[91] Freedburg, "US, UK Do 'Groundbreaking' Drone Exercise Off Scotland."

[92] Sydney Freedberg, "Semper Robotic: Marines Try Out New Tech, Tactics," *Breaking Defense*, October 20, 2016, accessed March 23, 2017, http://breakingdefense.com/2016/10/semper-robotic-marines-try-out-new-tech-tactics/.

[93] Associated Press, "Pentagon Tests Out 'Sea Hunter,'132-Foot Robot Ship," last modified May 3, 2016, accessed February 2, 2017, http://www.nbcnews.com/tech/tech-news/pentagon-tests-out-sea-hunter-132-foot-robot-ship-n566831.

[94] Sydney Freedberg, "Swarm 2: The Navy's Robotic Hive Mind," December 14, 2016, accessed February 2, 2017, http://breakingdefense.com/2016/12/swarm-2-the-navys-robotic-hive-mind/.

[95] Danny Collins, "Vlad's Drone Navy: Russia Testing New Drones that Could Scramble Sonars in the English Channel," *The Sun*, December 7, 2016, accessed February 2, 2017, https://www.thesun.co.uk/news/2347905/russia-testing-new-drones-that-could-scramble-sonars-in-the-english-channel-and-allow-nuclear-submarines-to-enter-undetected/.

[96] Dave Majumdar, "Russia vs. America: The Race for Underwater Spy Drones," *The National Interest*, last modified January 21, 2016, accessed February 2, 2017, http://nationalinterest.org/blog/the-buzz/america-vs-russia-the-race-underwater-spy-drones-14981.

3,280 feet.[97] Also, the Russians continue to test unmanned marine vehicles for both surface and subsurface targets. On November 27, 2016, the Russians tested an underwater nuclear tipped drone capable of "carrying a nuclear warhead up to 6,200 miles. The vehicle can submerge to a depth of 3,280 feet and travel at speeds of up to fifty-six knots" with the purpose of destroying enemy seaports.[98] Both Russian air and sea drone programs are intended to provide constant observation and targeting of potential adversaries, both capabilities drone swarms can enhance. The underwater vehicles are optimal for swarming an adversary's fleet or in the case of nuclear drones capable of destroying multiple cities at once. They are hard to detect and can converge, attack, and disperse quickly, enabling attacks on military vessels and civilian populations, creating unprecedented psychological shock to soldiers and civilians.

China has taken notice of US advances in surface and subsurface drones and their ability to swarm.[99] The PLA Navy is likely to develop their version of the Sea Hunter and are developing ways to counter US swarms by advancing their nuclear submarine fleet and systems to track and destroy the Sea Hunter.[100] Further, China looks to unmanned maritime swarms as ubiquitous sensors to identify, track, and potentially destroy enemy submarines.[101] The ubiquitous maritime drone swarms consist of unmanned underwater drones and sensors that act as an "Underwater Great Wall of China." The sensors are positioned on the sea floor and notify multiple USVs and UUVs of potential enemy submarines. The USVs and UUVs then confirm presence of potential submarines, track and attack the submarine, or notify

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[97] Bill Gertz, "Russia Tests Nuclear-Capable Drone Sub," *The Washington Free Beacon*, December 8, 2016, accessed February 2, 2017, http://freebeacon.com/national-security/russia-tests-nuclear-capable-drone-sub/.

[98] Bill Gertz, "Russia Tests Nuclear-Capable Drone: Unmanned underwater vehicle a strategic threat," The *Washington Free Beacon*, last modified December 8, 2016, accessed December 13, 2016, http://freebeacon.com/national-security/russia-tests-nuclear-capable-drone-sub/.

[99] Lyle J. Goldstein, "How China Sees the U.S Navy's Sea Hunter Drone," *The National Interest*, January 31, 2017, accessed February 2, 2017, http://nationalinterest.org/feature/how-china-sees-the-us-navys-sea-hunter-drone-19264.

[100] Ibid.

[101] Jeffrey Lin and P.W. Singer, "The Great Underwater Wall of Robots: Chinese Exhibit Shows Off Sea Drones," *Popular Science*, June 22, 2016, accessed February 4, 2017, http://www.popsci.com/great-underwater-wall-robots-chinese-exhibit-shows-off-sea-drones.

manned units of enemy presence.[102] Chinese USVs include unmanned boats up to thirteen meters long, with speeds up to eighty knots, and a range of 200 nautical miles. The armed unmanned boats are designed to swarm and chase targets, patrol ports and off-shore assets, conduct interdiction, and escort convoys.[103]

USVs and UUVs are not as available as UAVs and therefore, harder for non-state actors to acquire.[104] State actors like the United States, Russia, and China remain the most likely to operationalize unmanned maritime drone swarms. US Deputy Secretary of Defense Robert Work expects "to see unmanned systems undersea all over the place," and "on the surface of the sea" in the immediate future.[105] Like the air domain, the sea domain offers ample multi-directional maneuver space for drone swarms.

Drone swarming has taken its cue from both natural and human swarming. This insight sheds light on the strengths and vulnerabilities of drone swarming. Robotic and drone swarm developers use *biomimetics* to help better understand the similarities between natural swarms, human swarms, and drone swarms, in order to use technology to mimic natural swarming. With successful mimicry comes similar strengths and vulnerabilities. This chapter has highlighted a few current examples of drone swarming. The mechanical advantages of drone swarming are promising; however, like the ant, hornet, and human, drone swarms are not without vulnerabilities. The next chapter describes in detail the strengths, vulnerabilities, and future challenges of drone swarms.

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[102] Jeffrey Lin and P.W. Singer, "The Great Underwater Wall of Robots: Chinese Exhibit Shows Off Sea Drones."

[103] Jeffrey Lin and P.W. Singer, "For Sale: The Next Generation of Chinese War Robots," *Popular Science*, last modified April 28, 2016, accessed February 4, 2017, http://www.popsci.com/for-sale-next-generation-chinese-war-robots.

[104] Abbot et al., "Hostile Drones: The Hostile Use of Drones by Non-State Actors Against British Targets," 10.

[105] Phys.org, "No Plans for Killer US Military Robots…Yet," *Phys.org*, March 31, 2016, accessed February 4, 2017, https://m.phys.org/news/2016-03-killer-military-robots.html.

Chapter 3: Analysis

Drone swarms provide enhanced and ever-present ISR and target capabilities. Further, drone swarms afford low-risk to personnel and military decision makers, and low-cost to military organizations. Also, the novelty of drone swarms creates cognitive dissonance and physical tension and in turn, individual and organizational paralysis in decision making. The advantages of drone swarms present leverage to actors that are capable of operationalizing them. However, drone swarms are not impervious to military countermeasures like electronic and cyber threats (hacking) and are challenged by cultural resistance, organizational limitations, and ethical and legal constraints. This chapter answers what utility drone swarms bring to the military by examining their advantages, vulnerabilities, and challenges.

Drone swarm advantages and vulnerabilities are not only strategic but operational and tactical, and both offensive and defensive. In Army Training Publication (ATP) 3-01.8 *Techniques for Combined Arms Air Defense,* the US Army recognizes the drone swarm attack as "perhaps the most dangerous" against ground troops.[106] In ATP 3-01.8, the US Army prepares units to defend against a UAV platform's ability to conduct surveillance, indirect attacks, direct attacks, and swarms.[107] Further the US Department of Defense (DoD) recognizes the advantages of drone swarms. In 2017, the DoD announced the successful demonstration of a micro-drone swarm of 103 drones launched from F-18 fixed wing aircraft, and capable of "collective decision-making, adaptive formation flying, and self-healing."[108] What the US Army wants the 103 micro-drone swarm to do is conduct constant and ubiquitous loitering for ISR and target acquisition, and then utilize other drone swarms to overcome enemy defenses and destroy targets.[109]

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[106] Army Training Publication 3-01.8, *Techniques for Combined Arms Air Defense* (Washington, DC: Department of the Army, 2016), 3-12.

[107] Ibid, 3-9 to 3-13.

[108] Department of Defense Press Release, "Department of Defense Announces Successful Micro-Drone Demonstration," January 9, 2017, Release Number: NR-008-17.

[109] Kelsey D Atherton, "The Pentagon's New Drone Swarm Heralds A Future of Autonomous War

Advantages

Constant and ubiquitous drone swarm loitering delivers ISR capabilities that provide persistent informational flow between systems resulting in timely and accurate situational awareness of the strategic and operational environment, to include signal and communications intelligence, and battle damage assessments.[110] Persistent information allows units to acquire enemy locations almost instantaneously depending on the size of the drone swarm, to acquire targets and destroy them with mass of fires. At sea, drone swarms increase the likelihood of locating adversarial ships farther out and can track or attack continuously.[111] Additionally, units can utilize drone swarms as weapons for precision strikes or electronic warfare, reducing the ability of an adversary to move and maneuver without being observed and immediately targeted. Harris's hawks, a bird of prey, provide a natural example of what constant drone swarm targeting provides the military. Harris's hawks swarm prey by conducting simultaneous attacks on the target, who may escape the first hawk, but is then attacked again and again seconds later by subsequent hawks.[112] If the prey goes to ground, the hawks hover over the hiding spot taking turns to penetrate cover. Once the prey is flushed out, surrounding hawks swoop in on the prey.[113] Drone swarms offer similar utility to the military. As David Hambling states in his book *Swarm Troopers*, an adversary may be able to hide from drone swarms, but the drone swarms will still be there when he eventually comes out.[114]

Machines," *Popular Science*, January 10, 2017, accessed on February 19, 2017, http://www.popsci.com/pentagon-drone-swarm-autonomous-war-machines.

[110] United States Air Force, Office of the Chief Scientist, "Autonomous Horizons," 14.

[111] Easton and Hsiao, *The Chinese People's Liberation Army's Unmanned Aerial Vehicle Project: Organizational Capacities and Operational Capabilities*, 11-14.

[112] William Cook, *Avian Desert Predator* (Berlin: Springer Berlin Heidelberg, 1996).

[113] Ibid.

[114] David Hambling, *Swarm Troopers: How Small Drones Will Conquer the World* (Venice, FL: Archangel Ink, 2015), 240.

Drones and drone swarms are cheap and expendable, while human beings are not. Risk management is a cornerstone of military operations and is partially used in identifying and controlling potential hazards that pose unnecessary risk to personnel.[115] At the strategic and political level, mounting casualties create political risk, which can be mitigated by drone employment. Conversely, at the operational level drone swarms can enhance prudent risk. The speed, ubiquity, and prevalence of drone swarms afford advantages in the principles of offensive, mass, maneuver, economy of force, security, and surprise.

Additionally, drone swarms reduce the monetary cost of war. Not counting the cost of training pilots or maintaining aircraft, the least expensive US Air Force fighter, the F-16, costs $18 million dollars.[116] The US Navy will build to 308 ships in thirty years, for $509 billion.[117] In 2014, each service member deployed to Afghanistan cost $2.1 million.[118] Drones are orders of magnitude cheaper. Given that the average UAV costs $600, even the most expensive drone swarm planned, a US Navy concept of 1000 drones, would still cost 97% less than a single F-16. [119]

Another advantage of drone swarms is they provide operational shock to an adversary's military system. Operational shock originated in the 1920s, thanks to Soviet military theorist Mikhail Nikolaveich Tukhachevskii and others, as a means of systems disruption (*udar*).[120] Prior to the 1920s, the prevailing military approach was the "phenomenon of mass" in which "numerical superiority is the guarantee of

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[115] Army Techniques Publication, Number 5-19 (ATP 5-19) *Risk Management* (Washington, DC: Department of the Army, 2014), v.

[116] US Airforce, "Factsheets," February 26, 2017, accessed February 26, 2017, http://www.af.mil/AboutUs/FactSheets.aspx.

[117] Congressional Budget Office, *An Analysis of the Navy's Fiscal Year 2017 Shipbuilding Plan*, (Washington DC, 2017), https://www.cbo.gov/publication/52324.

[118] Todd Harrison, "Chaos and Uncertainty: The FY2014 Defense Budget and Beyond," *Center for Strategic and Budgetary Assessment (CSBA)* (Washington, DC: CSBA, 2013), 11.

[119] Chris Abbott et al., *Hostile Drones: The Hostile Use of Drones By Non-State Actors Against British Targets* (London: Remote Control Project, 2016), 1-24.

[120] Shimon Naveh, *In Pursuit of Military Excellence: The Evolution of Operational Theory* (London: Frank Cass Publishers, 1997), 11.

victory."[121] The total destruction of the enemy's military system, generally the army, became the aim. In a linear, compact environment, where entire armies faced one another on the same terrain, annihilation of an enemy army remained possible. However, modern warfare and technology has forced units and military systems to disperse, transforming and expanding the linear condensed battlefield into one of non-linearity and depth. Tukhachevskii had an answer in deep operation theory, centered on operational shock, moving the course of warfare from attrition to maneuver, and from physical destruction to cognitive paralysis "attained by a succession of blows aimed at the rival system's depth" and shocking "the cognitive fabric of the rival systems behavior" lending to paralysis.[122] An important element of operational shock is simultaneity, where drone swarms have maximum effect.

Tukhachevskii used simultaneity as an operational swarm by combining a frontal fixing force, a maneuver ground and air strike force that disrupted the enemy rear, all attacking the enemy simultaneously from multiple directions.[123] The operational swarm prevented the enemy from maneuvering and defending himself, thus paralyzing his system. The ubiquitous lethality of drone swarms offers parallel methods and results. T.X. Hammes alludes to the drone swarm's ubiquitous lethality in that drone swarms are capable of instantaneously killing anybody or anything that moves on land, air, or sea, precluding movement and maneuver and "may make the defense the dominate form of warfare in ground, air, sea, and space domains." [124] Like operational shock, drone swarms preclude movement, maneuver, and defense, begetting systems paralysis and failure.

[121] Naveh, *In Pursuit of Military Excellence: The Evolution of Operational Theory*, 35.

[122] Ibid, 184.

[123] Ibid, 215-216.

[124] T.X. Hammes, "Technologies Converge and Power Diffuses: The Evolution of Small, Smart, and Cheap Weapons," *Policy Analysis* no. 786 (January 27, 2016): 1-10.

Additionally, drone swarms provide cognitive dissonance and decision making paralysis to tactical and operational military decision makers. Walter Cannon's "fight or flight" and John Boyd's view of mental isolation provide a suitable lens for further explanation. When reality is inconsistent with an individual's expectations, the individual experiences a cognitive dissonance, an inner turmoil of stress and chaos.

Walter Bradford Cannon's concept of "fight or flight," a physiological response to cognitive, dissonance helps explain how human beings might react to a drone swarm. Fight or flight is the physiological reaction in response to a perceived or real threat to survival.[125] According to Cannon, the sympathetic nervous system prepares humans to fight or flee when confronted with a threat.[126] In this, an individual gains a perception of losing control resulting in anxiety and aggression.[127] Naveh speaks to the loss of control posed on a military commander when facing operational shock: "recognizing his inability to control the situation," the commander's decision-making freezes.[128] The freeze response is tied to "fight or flight" in which individuals are overcome by a stimuli, and the individual shuts down, incapable of making decisions.

Shock and paralysis is what drone swarms provide the military and is congruent with Phillip Karber's and Joshua Thibeault's assessment of Russian UAV impacts on Ukrainian military forces. Karber and Thibeault state "the constant awareness of being observed and targeted" by Russian drones that loiter almost ubiquitously "is often a traumatic experience that instills fear and inhibits movement" and decision-making.[129] Further, Karber notes the Ukrainians know "when they see certain types of

[125] Walter Cannon, *Wisdom of the Body* (New York, NY: W.W. Norton and Company, 1932), 20.

[126] Arthur Janse et al., "Central Command Neurons of the Sympathetic Nervous System: Basis of the Fight or Flight Response," *Science Magazine*, October 27, 1995, 270.

[127] Mara Brendan et al., "Is There a Dark Side of Positive Illusions? Overestimation of Social Competence and Subsequent Adjustment in Aggressive and Nonaggressive Children," *Journal of Abnormal Child Psychology* 32, no. 3 (June 2004): 305-20.

[128] Naveh, *In Pursuit of Military Excellence: The Evolution of Operational Theory*, 212.

[129] Karber and Thibeault, "Russia's New Generation Warfare."

UAVs…there're going to be rockets landing on top of them."[130] This bombardment of fires most certainly provides sensory overload to military decision makers, and to individual paralysis. However, the shock of drone swarms must be amplified in order to maintain paralysis.

John Boyd provides a framework, the observe, orient, decide, act cycle (OODA loop), that provides a method to amplify drone swarms through positive feedback loops. In its simplest form, the OODA loop is a decision making framework that provides the belligerent who progresses through the loop the fastest an advantage over an opponent.[131] *In Science, Strategy and War: The Strategic Theory of John Boyd*, Frans P.B. Osinga argues the OODA loop is much more than a decision making framework; the OODA loop is one supporting concept of a "more, comprehensive, deeper, and richer" theoretical and strategic framework.[132] Ozinga uses Boyd's *Patterns of Conflict* to highlight his theoretical framework:

> The game is to create tangles of threatening and/or non-threatening events/efforts as well repeatedly generate mismatches…and penetrate [an] adversary organism to sever his moral bonds, disorient his mental images, disrupt his operations, and overload his system, as well as subvert, shatter seize, or otherwise subdue those moral-mental-physical-bastions, connections, or activities that he depends on…[to] pull [the] adversary apart, produce paralysis, and collapse his will to resist.[133]

Ozinga continues by quoting Boyd's *Destruction and Creation*, specifically how fluidity and novelty enable complexity:

> (technical, organizational, operational, etc) [that] causes commanders and subordinates alike to be captured by their own internal dynamics or interactions—hence they cannot adapt to rapidly changing external (or even internal) circumstances…[and] enmesh [an] adversary in a world of uncertainty, doubt, mistrust, confusion, disorder, fear, panic, chaos…and/or fold an adversary back inside himself so that he cannot cope with events/efforts as they unfold.[134]

What Boyd describes above is a form of what he calls the "mental isolation" of an adversary which occurs when they are presented with "ambiguous, deceptive or novel situations, as well as by

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[130] Freedburg, "Swarm 2: The Navy's Robotic Hive Mind."

[131] Frans P.B. Osinga, *Science, Strategy and War: The Strategic Theory of John Boyd* (New York: Routledge, 2007), 1.

[132] Ibid, 7.

[133] Ibid, 185.

[134] Ibid, 186.

operating at a tempo or rhythm they can neither make or keep up with…"[135] It is within fluidity and novelty that drone swarms enable flexibility and adaptability for friendly commanders and unmanageable complexity for the enemy.

Antoine Bousquet appreciates the fluidity and adaptability of drone swarms, and believes they provide a balance "between control and predictability" and "adaptability and resilience." Bousquet believes "the fluidity of swarms allow…forms of social organization to adapt more rapidly and effectively to the unforeseen." Bousquet cites Glen James' book *Chaos Theory: The Essentials for Military Applications* that the "battlespace of the future may see…fire ant warfare in which swarms composed of millions of sensors, emitters, microbots, and micro-missiles and…saturate the terrain of conflict" where drone swarms are "able to converge on all directions for offensive bursts…maximizing the shock effect."[136] With Boyd's OODA loop in mind, drone swarms enhance the commander's ability to observe, orient, decide, and act more rapidly than the enemy with "the game" to isolate him physically, mentally, and morally, producing paralysis and collapsing his will before he can make a decision to return in kind.

The sight of seeing a drone swarm for the first time provides the novelty Boyd seeks to in his writings and thus enables "mismatches" or the "shock effect" in the adversary's cognitive cohesion, disrupting his "mental images…overloading his system," producing cognitive paralysis that results in "uncertainty, doubt, mistrust, confusion, disorder, fear, panic, chaos."[137] As discussed with operational shock, the "freeze response" and the Ukrainians' fear and cognitive dissonance of being watched all the time, drone swarms shape individual and collective systems, and can shock and paralyze individual adversaries and lead their systems to entropy and death. Boyd understood the importance of feedback, specifically the necessity to continually dampen an enemy's ability to decide, while amplifying one's own

[135] Frans P.B. Osinga, *Science, Strategy and War: The Strategic Theory of John Boyd*, 214.

[136] Antoine Bousquet, *The Scientific Way of Warfare: Order and Chaos of the Battlefields of Modernity* (New York: Columbia University Press, 2009), 213.

[137] Osinga, *Science, Strategy and War: The Strategic Theory of John Boyd*, 186.

decision making. Yet Boyd also understood that human beings and systems eventually adapt, and therefore, any advantages drone swarms provide are only temporary.

Vulnerabilities

Drone swarms face both physical and cognitive vulnerabilities. Electronic jamming, lasers, rail guns, smart bullets, cyber-attacks, other drone swarms, and dispersion are some available methods to contest drone swarms. Psychological resilience and adaptability offer a cognitive test to the novelty and psychological effects of drone swarms. As complex adaptive systems, humans, even in the most stressful, unfamiliar, and complex environments, can adapt and "harness" novelty and the cognitive challenges novelty imposes.[138] In the spirit of Norbert Weiner's *Cybernetics* and John Boyd's theory, these vulnerabilities, both physical and cognitive, provide a dampening of the positive effects of drone swarms.

The USS Ponce is equipped with the Laser Weapon System (LaWS) to defend against drones. The US Air Force wants lasers on their planes by 2020, for among other things, to shoot down drones.[139] The US Army and Marines are looking to equip helicopters and trucks with lasers. Lasers are accurate and are "low cost-per-shot," about one-dollar.[140] In April 2016, the US Army tested a 10-kilowatt laser blaster, attached to the back of a truck, to shoot down a drone.[141] Lasers are cheap, efficient, and effective; however, they are vulnerable to weather, mirrors, take time to destroy a single drone (about 15 seconds) and therefore, would be hard pressed to destroy a drone swarm. For example, David Hambling posits "if a drone swarm approaching at 120 mph is engaged from two miles away, the defenders have one minute to stop it with a laser.[142]

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[138] Robert Axelrod and Michael D. Cohen, *Harnessing Complexity* (New York: The Free Press, 2000), 7-9.

[139] Kelsey Atherton, "Air Force Wants Lasers on Large Planes by 2022, *Popular Science*, May 9, 2016, accessed March 14, 2017, http://www.popsci.com/air-force-wants-lasers-on-large-planes-by-2022.

[140] David Hambling, "Drones Fight Back Against Laser Weapons," *Popular Science*, November 4, 2016, accessed March 14, 2017, http://www.popsci.com/laser-guns-are-targeting-uavs-but-drones-are-fighting-back.

[141] Joseph Trevithick, "US Army Laser Chief—'We Absolutely Blew Lots of Stuff up'," *War is Boring*, May 19, 2016, accessed March 14, 2017, https://warisboring.com/u-s-army-laser-chief-we-absolutely-blew-lots-of-stuff-up-a5c3a2f6a23c.

[142] Hambling, "Drones Fight Back Against Laser Weapons."

Microwave weapons, like the US Army's "Phaser," avoid the vulnerabilities of lasers. The "Phaser" identifies enemy drone swarms and beams high-power microwaves at the swarm, destroying the swarms' control systems.[143] Recently, DARPA announced a contract with Raytheon to build smart-bullets that are capable of altering their path mid-flight to engage multiple targets, including UAV and USV drone swarms.[144] Similar to microwave weapons, smart bullets do not require aiming directly at the target, only in the general direction of the swarm. Also, the US Army is planning on using a massive rail gun, "basically a larger version of the 25-millimeter Bushmaster used [on] the M-2 Bradley…that can fire up to 200 rounds every minute" to counter enemy drone swarms.[145]

As well, drone swarms can fall to hackers or cyber-attacks. In 2009 Iraqi insurgents were able to intercept a Predator feed using a $30 software package.[146] Given that current unmanned vehicles require communications links, they are susceptible to remote "hijack."[147] Adversaries can jam or shut down networks and sensors, including drone swarms, so the operator can't see anything at all.[148] In his book *Military Robots and Drones*, Robert Springer warns that since unmanned systems are run by computer programs, they "might be susceptible to cyber-attack and reprogramming…hostile alteration, as any victim of a computer virus can attest."[149] Springer contends that "autonomous combat systems offer the possibility to create a consummate double agent or sleeper, appearing to function normally until a critical

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[143] Jennings Brown, US Develops 'Phaser' to Shoot Terrorist Drones Out of the Sky," *Vocativ*, November 16, 2016, accessed March 14, 2017, http://www.vocativ.com/376356/phaser-stop-drone-swarm/.

[144] Jerome Dunn, "Multi-Azimuth Defense Fast Intercept Round," Defense Advanced Research Projects Agency, accessed March 14, 2017, http://www.darpa.mil/program/multi-azimuth-defense-fast-intercept-round-engagement-system.

[145] Joseph Trevithick, "The US Army Wants to Blast Drones Out of the Sky with a Huge Chain Gun: Cannon Spews Guided Ammunition to Hit Low-Altitude Targets," *War is Boring*, July 10, 2015, accessed March 14, 2017, https://warisboring.com/the-u-s-army-wants-to-blast-drones-out-of-the-sky-with-a-huge-chain-gun-18cfac25e76a#.90izr494l.

[146] Springer, *Military Robots and Drones*, 48.

[147] Ibid.

[148] Sydney Freedburg, "Army Electronic Warfare 'Is a Weapon—But Cyber is Sexier," *Breaking Defense*, October 16, 2014, accessed March 14, 2017, http://breakingdefense.com/2014/10/army-electronic-warfare-is-a-weapon-but-cyber-is-sexier/.

[149] Springer, *Military Robots and Drones*, 48.

moment, when a malfunction or loss of operator control can yield devastating results."[150] Drone swarms may be more susceptible to cyber-attack than single drones due to the volume of electronic links and access points.

Additionally, drone swarms are vulnerable to static dispersion, deception, and other unmanned swarms. Drone swarms provide significant advantages over an adversary, to include limiting movement and maneuver, but an adversary is likely to adapt by dispersing forces or staying put. T.X. Hammes notes drone swarms may force a shift to "tactically dominant defense" where no individual or unit moves, as in trench warfare.[151] Deception, not including hacking or spoofing, is a somewhat unique countermeasure to drone swarms. Robotics, to include drones, are programmed to recognize patterns (e.g. terrain, movement) and behave according to these patterns. Springer notes "smoke, camouflage, and false heat signatures…foil automated systems."[152] Another challenge to human swarming that is applicable to drone swarms are other swarms. We saw with natural and human swarming that the best defense is often other swarms. The advantages of drone swarms are numerous, but mitigated and potentially neutralized when facing a weapon that is just as numerous, fast, and effective. In January 2017, the US Naval Postgraduate School conducted a fifty on fifty drone swarm dogfight to advance effectiveness of drone swarm self-organization, the result was a tie.[153] Similar testing and planning is underway for unmanned surface vessels and ground vehicles. For example, in anticipation of a mass of attacking naval groups, the Project 2049 Institute reports "Chinese strategists plan to use drones of swarms in a variety of ways to defeat opposing naval forces."[154]

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[150] Springer, *Military Robots and Drones*, 48.

[151] Hammes, "Technologies Converge and Power Diffuses: The Evolution of Small, Smart, and Cheap Weapons."

[152] Springer, *Military Robots and Drones*, 47.

[153] Javier Chagoya, "Academic Partners Take to the Skies in First-Ever UAV Swarm Dogfight," Naval Postgraduate School, February 22, 2017, accessed March 16, 2017, http://nps.edu/About/News/NPS-Academic-Partners-Take-to-the-Skies-in-First-Ever-UAV-Swarm-Dogfight.html.

[154] Easton and Hsiao, *The Chinese People's Liberation Army's Unmanned Aerial Vehicle Project: Organizational Capacities and Operational Capabilities*, 14.

A final vulnerability is a human being's ability to cope and adapt to novelty, to include technology, and remain resilient to its effects. Eventually, the effects of novelty wear off, including drone swarms.[155] As complex adaptive systems, human beings harness complexity through various mechanisms, to include coping. Nassim Taleb argues "some things benefit from shocks; they thrive and grow when exposed to volatility, randomness, disorder, and stressors…" Taleb describes these type of people as "antifragile." [156] In fact, as John Holland notes, human beings are complex adaptive systems and, "are characterized by perpetual novelty."[157] Bottom line, humans may be able to adapt, cope, bounce back, and overcome the novelty of drone swarms.

Challenges

The last section dealt mainly with external problems facing drone swarms, this section analyzes primarily US internal challenges to employing drone swarms, including technological dependence, cultural/organizational resistance and bias, legal/ethical considerations, inter-service tension over ownership, and unit task organization. With respect to technological dependency, drone swarms can create an impression that war can be won on the cheap and easy. John Lynn alludes to the overreliance on technology in that it "mesmerizes" military strategists into believing "military hardware surpasses all other factors in war."[158] Joseph Nye offers analysis on technological dependence in *The Future of Power*, highlighting the success of the technologically centered "revolution in military affairs" in Desert Storm, and its initial success in Afghanistan and Iraq as a catalyst for failure later in these conflicts.[159]

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[155] David Straker, "Adaptation," Changing Minds.org, accessed April 16, 2017, http://changingminds.org/explanations/behaviors/coping/adaptation.htm.

[156] Nassim Taleb, *Antifragile: Things That Gain from Disorder* (New York: Random House, 2012), 4.

[157] Cited in Ozinga, *Science, Strategy and War: The Strategic Theory of John Boyd*, 138.

[158] John Lynn, *Battle* (Boulder, CO: Westview Press, 2003), xix.

[159] Joseph Nye, *The Future of Power* (New York: PublicAffairs, 2011), 35-36.

Nye provides two "costs of putting too much faith in technology."[160] The first cost is what Nye describes as a double-edged sword, where technology "eventually spreads and becomes available to adversaries with more primitive capabilities but are less vulnerable to dependence…"[161] Further, Nye argues robotics and unmanned vehicles are eventually mitigated because of increased availability to all actors.[162] A second cost is "too much faith and focus on the advantages of technologies…divert attention" away from asymmetrical and unconventional warfare.[163] Everett Dolman calls asymmetric warfare the "bane" of technologically superior militaries because they lose sight of what it takes to win "bloody [and] brutal" unconventional wars.[164]

Perhaps the biggest challenge to drone swarms is cultural and organizational resistance and bias. Dependence on technology has become synonymous with the "revolution of military affairs (RMA)" which has left some to reject and conflate the importance of the "revolution" and technology, and point to Afghanistan, Iraq, and Israel's war with Hezbollah in 2006 as the failure of RMA and technological dependence.[165] Consequently, military opponents of RMA have used its recent "failures" as evidence to support the necessity of human involvement.

Self-serving bias and organizational culture also pose problems. For example, In *Tomorrow's Air Force: Tracing the Past, Shaping the Future*, Jeffery Smith cites cultural resistance as a leading factor, not only to the drone pilot, but to drones themselves.[166] Smith's study claims "the fighter operations perspective still dominates" the Air Force and many drone pilots perceive a "self-serving bias" within the

[160] Nye, *The Future of Power*, 36.

[161] Ibid.

[162] Ibid.

[163] Ibid.

[164] Everett Dolman, *Pure Strategy: Power and Principles in the Space and Information Age* (New York: Taylor and Francis Group, 2005), 134.

[165] Avi Kober, "The Rise and Fall of Israeli Operational Art, 1948-2008," in *The Evolution of Operational Art*, ed. John Olsen and Martin Van Creveld (Oxford: Oxford University Press, 2011), 189-190.

[166] Jeffrey J. Smith, *Tomorrow's Air Force: Tracing the Past, Shaping the Future* (Bloomington: Indiana University Press, 2014), 201.

fighter culture that promotes from within and looks down on drone pilots with "disgust."[167] Others argue too many drones degrade manned platforms and there are missions for which manned platforms are better suited for than drones.[168] Conversely, proponents of drones and drone swarms cite the termination of the US Air Force "Ryan Firebee" drone program in the 1970s, when despite superior performance over manned platforms in "dogfights," the program was terminated. Similarly, the US Navy either discontinued drone programs or failed to acquire them, claiming manned aircraft met requirements. In contrast, proponents of drones and drone swarms should not underestimate the importance of a "self-serving bias" for reasons of job security and organizational survival. Nor should they take lightly the political implications of allowing drones to dominate capabilities that currently belong to human beings.

Further, drone swarms are predominantly controlled through autonomous intelligence, with little or no human control, which brings resistance not only from the military community, but from others who question the legal and ethical implications of autonomous drone swarms. In the legal realm, domestic challengers are concerned with surveillance and intrusion in personal lives and potential violations of the Fourth Amendment, as well as the constitutionality of targeting American citizens overseas who happen to be members of terrorist organizations (such as Anwar Al-Awlaki).[169] Internationally, Yemen and Pakistan steadfastly accuse that drone strikes are a violation of national sovereignty. International law has failed to catch up with the advance of drones and many argue the United States and near peers have used this legal ambiguity to muscle the law to their advantage.[170] Others argue that the legal ambiguity of drone warfare requires a need to rethink the notion of privacy, liberty, and security (domestically), and

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[167] Smith, *Tomorrow's Air Force: Tracing the Past, Shaping the Future;* Michael Byrnes, "Dark Horizon: Airpower Revolution on a Razor's Edge—Part Two of the "Nightfall" Series," *Air & Space Power Journal*, September-October 2015, 35-36.

[168] Richard Whittle, "Army's Got Enough Drones; New Ones Should Be VTOL, Lundy says," Breaking Defense, January 14, 2016, accessed March 15, 2017, http://breakingdefense.com/2016/01/armys-got-enough-drones-new-ones-should-be-vtol-lundy-says/.

[169] Benjamin Wittes and Gabriella Blum, *The Future of Violence: Robots and Germs, Hackers and Drones, Confronting a New Age Threat* (New York: Basic Books, 2015), 188; Springer, *Military Robots and Drones*, 216.

[170] James Cook, "'Cyberation' and Just War Doctrine: A Response to Randall Dipert," *Journal of Military Ethics* 9, no. 4 (December 16, 2010): 421.

legal jurisdiction and sovereignty (internationally) that "allow states to defend themselves and their citizens against harm from others without turning the globe into the Wild West."[171]

Ethical implications of drone swarms are just as challenging. Some military ethicists posit using drones is a moral imperative and obligatory since ideally drones save human lives.[172] Others believe robots, to include drones, are better equipped than humans to fight ethically, and therefore drones and drone swarms are a necessity.[173] Some posit that the ambiguity and novelty of drones fall outside traditional international law and ethics.[174] Conversely, opponents argue drones make going to war too easy, unfair to less advanced countries, and fall outside the *jus ad bellum* of last resort and proportionality.[175] Also, opponents do not believe there is clear evidence that robots can behave more ethically than humans.[176] Further, opponents do not think drones are any more novel than other advanced weapons throughout history, and therefore traditional law and ethics do still apply.[177]

Lastly, drone swarm proponency and task organization are two challenges that warrant discussion. This monograph has highlighted drone swarm programs of various countries and non-state actors, and drone programs of different services within the US military. The challenge is that each US service is developing a drone swarm program independent of each other. Inter-service tribalism and protectionism is not new; the challenge is how to utilize and integrate drone swarms into Joint doctrine that clearly defines which service is responsible for which drone swarms.

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[171] Wittes and Blum, *The Future of Violence: Robots and Germs, Hackers and Drones, Confronting a New Age Threat* (New York: Basic Books, 2015), 172-173.

[172] Bradley Jay Strawser, "Moral Predators: The Duty to Employ Uninhabited Aerial Vehicles," *Journal of Military Ethics* 9, no 4, (2010): 342-68.

[173] Ronald Arkin, "The Case for Ethical Autonomy in Unmanned Systems," *Journal of Military Ethics* 9, no. 4, (2010): 332-41.

[174] Randall Dipert, "The Ethics of Cyberwarfare," *Journal of Military Ethics* 9, no. 4 (2010): 384-410.

[175] Jai Galliot, "Uninhabited Aerial Vehicles and the Asymmetry Objections: A Response to Strawser," *Journal of Military Ethics* 11, no. 1 (November 12, 2013): 58-66.

[176] Ryan Tonkens, "The Case Against Robotic Warfare: A Response to Arkin," *Journal of Military Ethics* 11, no. 2 (September 10, 2012): 149-68.

[177] Cook, "'Cyberation' and Just War Doctrine: A Response to Randall Dipert," 411-23.

Employment of drone swarms pose challenges to adversaries, but also come with risks. Drone swarms challenge an adversary's ability to move without being identified and can provide operational shock to their personnel and military systems. Compared to manned vehicles, drone swarms are inexpensive and less risky for military organizations and personnel. Yet hackers can exploit drone swarms and certain weapons can destroy them. Also, legal, ethical, and cultural factors limit drone swarm employment. The following chapter highlights a few recommendations on how to best employ drone swarms.

Chapter 4: Recommendations and Conclusion

The aim of this chapter is to provide recommendations on the employment of drone swarms. The recommendations include the need for a drone swarm narrative that educates military practitioners, development of drone swarm doctrine, understanding of autonomous and human interface, and the planning of drone swarm integration into military units.

Narrative

The purpose of a narrative is to tell a story. Currently, the drone swarm narrative resides in science fiction. Books like *Ghost Fleet* and movies such as *Star Trek* carry a narrative that employment of drone swarms is far off and far out. Chapter Two shows this science fiction narrative is false. Despite facts, the science fiction narrative resonates, and for the military to take drone swarms seriously, it is necessary to change the story. Changing the story requires a narrative that normalizes drone swarms. In his book, *The Cambridge Introduction to Narrative*, H. Porter Abbott believes normalizing requires a narrative that brings a collection of events together in a story and "renders them plausible."[178] The events in the case of drone swarms can include a historical context of swarming and drones that provides insight into drone swarms and their employment. Other relevant events are the current state of drone swarm employment and programs, when drone swarms are projected to be operational, and their purpose in the near future and long-term. These are only examples; what should be considered is a narrative that normalizes drone swarms, not only with individual personnel, but within the military system. The acceptance of drone swarms takes time, and drone swarms will meet resistance, but a narrative that provides a plausible story helps to change individual and systemic paradigms. More so, a narrative provides an understanding of drone swarms and how they fit into the military system, bringing drone swarms to life into the present, and away from science fiction.

[178] H.Porter Abbott, *The Cambridge Introduction to Narrative* (Cambridge: Cambridge University Press, 2008), 44.

Drone Swarm Doctrine

Doctrine is perhaps the best place for this narrative. According to Joint Publication 1 (JP 1), *Doctrine for the Armed Forces of the United States*, the purpose of doctrine is "to enhance the operational effectiveness of joint forces by providing fundamental principles that guide the employment of US military forces toward a common objective."[179] It is hard to apply "fundamental principles" to drone swarms when there is no precedent. Carl von Clausewitz is less prescriptive in his interpretation of doctrine, and perhaps is more apt to drone swarms, claiming doctrine as a framework for employment of means and their effects.[180] The development and application of a Joint swarm doctrine would set a precedent, and establish a frame of reference for practitioners to effectively employ drone swarms.

Drone swarm doctrine can draw from Arquilla, Rosenfeldt, and Edwards who have advocated for swarming for nearly two decades. Their "Battles Swarm" can be used as a framework for drone swarm doctrine. Also, DARPA has initiated the Offensive Swarm-Enabled Tactics (OFFSET) with the goal according to project manager Timothy Chung, to "quickly generate swarm tactics, evaluate those swarm's tactics for effectiveness, and integrate the best swarm tactics into field operations."[181] The US Army has provided a strategy which aims to employ autonomous and semi-autonomous drones to increase situational awareness, lighten soldiers' physical and cognitive workloads, sustain the force, facilitate movement and maneuver, and protect the forces. Similarly, the US Air Force has a "path to the future" for autonomous drones.[182] This guidance can help drive drone swarm doctrine to ensure the employment of drone swarms fall within the parameters of both military strategy and policy aims.

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[179] Joint Chiefs of Staff, Joint Publication 1, *Doctrine for the Armed Forces of the United States* (Washington, DC: Government Printing Office, 2013), ix-x.

[180] Carl von Clausewitz, *On War*, ed. Michael Howard and Peter Paret (Princeton: Princeton University Press, 1976), 141.

[181] DARPA, Press Release: OFFSET Envisions Swarm Capabilities for Small Urban Ground Units, December 7, 2016, accessed March 15, 2017, http://www.darpa.mil/news-events/2016-12-07.

[182] US Army, "The US Army Robotic and Autonomous Systems Strategy," 1.

Drone and Human Interface

An additional recommendation is to begin study on the relationship between autonomous and semi-autonomous robotics including drones and humans. For the foreseeable future, drone swarms will not be fully autonomous but will have humans as decision makers. There is a strong argument that human beings "in the loop" only slows drone swarm efficiency, and fully autonomous drone swarms are the way to go; however, the current legal, ethical, and political landscape does not allow for fully autonomous swarms. Further, drone swarm software is still in development, and has yet to reach a point that allows drone swarms to tackle increasingly complex problems.[183] The US Air Force suggests autonomy is not all or nothing and provides a spectrum from full human control, semi-autonomy, to full autonomy depending on the mission, for example, full autonomy for "data fusion," semi-autonomy for object recognition, and human decision making for targeting.[184] The Air Force example is just one of many scenarios. What is important is that the military begins understanding, defining, and preparing how autonomous or semi-autonomous robotics and vehicles will interface with their human controllers.

Drone Swarm Integration

The final recommendation is that each service should begin reviewing, surveying, and planning for how to integrate drone swarms into their modified tables of organization and equipment (MTOE) or equivalent, and how drone swarms will be task organized. The US Army does not foresee human and drone swarm interface until at least 2021; however, this long-term projection does not preclude planning and preparing changes to unit and task organization.[185] Changing a unit's task organization or MTOE can take years. Therefore, services should begin planning and preparing now. Time is imperative; the Chinese PLA has "developed an extensive and organizationally complex UAV infrastructure over the past

[183] US Air Force, Office of the Chief Scientist, "Autonomous Horizons," 5.

[184] Ibid, 10.

[185] US Army, "The US Army Robotic and Autonomous Systems Strategy," 7.

decade…and now fields one of the world's most expansive UAV fleets."[186] Further, it appears the PLA has modified and modernized the Army, Navy, and Air Force with subordinate UAV units, from company to regimental level.[187]

Drone swarms look impressive and promising; a plausible narrative, drone swarm doctrine, and a plan for drone swarm integration can help maintain the outlook. Like any technology, drones and drone swarming are advancing quickly. Further study on nano and micro drone technology can provide a better understanding of drone swarms, to include nano-swarms, which are on the horizon, and are harder to detect, track, and neutralize.[188] Further, they are faster and more agile than larger drones, and can go places other drones cannot (swarms inside buildings).[189] Virtual swarming also offers potential military utility. Through its OFFSET program, DARPA has initiated a program that parlays virtual reality to control drone swarms.[190] The concept of "Virtual Mass" or diffused warfare espoused by Yedidia Groll-Yaari and Haim Assa, is a form of warfare in response to asymmetric enemies and warrants further inquiry. Virtual mass is being everywhere at once, imposing the maximum amount of friction on the enemy's system, a modified and modernized deep battle, where military units are dispersed or diffused, however, are networked and "where ships, combat planes, UAVs, ground vehicles, and infantry troops, are all independent entities, with equal functions and connectivity."[191] The future study of nano-swarms, virtual swarming, and virtual mass can all build on the phenomenon of drone swarms, and provide a framework for continuous development of drone swarm doctrine.

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[186] Easton and Hsiao, *The Chinese People's Liberation Army's Unmanned Aerial Vehicle Project: Organizational Capacities and Operational Capabilities*, 11-14.

[187] Ibid.

[188] Hitoshi Nasu, "The Future of Nanotechnology in Warfare," *The Global Journal*, July 4, 2013, accessed March 22, 2017, http://www.theglobaljournal.net/article/view/1132/.

[189] K. Eric Drexler, *Engines of Creation: The Coming Era of Nanotechnology* (New York: Anchor Books, 1986), 1.

[190] DARPA, Press Release: OFFSET Envisions Swarm Capabilities for Small Urban Ground Units, December 7, 2016, accessed March 15, 2017, http://www.darpa.mil/news-events/2016-12-07.

[191] Yedidia Groll-Yaari and Haim Assa, *Diffused Warfare: The Concept of Virtual Mass* (Haifa: University of Haifa, 2007), 69-73.

A proper narrative is necessary because it can educate, inform, and change individual and systemic perspective and attitudes towards drone swarms. When developing drone swarm doctrine and preparing for ways to use them, integration of drone swarms into military units should take place simultaneously. Drone swarms currently show promise, but for now they are a technological capability, a weapon, without context or framework as to how to effectively employ them. This monograph provided some context, current capabilities, and a few recommendations on how to effectively employ drone swarms. Further, a drone swarm narrative, doctrine, and integration plan combined with future study on other forms of drone swarming can help develop this promising military capability.

Conclusion

Drone swarming is the descendant of millions of years of lineage. Nature provides a rich abundance of examples, from ant swarms to Giant Japanese Hornet swarms, from fish schools to bird flocks. Human beings have shared in swarming, and provide many historical examples from the Mongols to Napoleon. Unmanned weapons and vehicles have been used all around the world for centuries, and are the forbearers of modern drones. Swarming and drones come with opportunity and risk, each garnering superiority against certain foes and vulnerabilities against others. The potential of drone swarms is both exponential and finite. Therefore, not only is it important to seek and learn from past and current swarmers, but to look to the future of swarming, which includes nano/micro drone swarms and virtual swarming among others. Drone swarms are coming to a military theater soon. It is not a matter of *if* drone swarms become reality, it is a matter of when, where, and "who can out-innovate faster than everyone else." [192]

[192] Ashton Carter, "Keynote Address: The Path to the Innovative Future of Defense," lecture, Center for Strategic and International Studies, Washington, DC, October 28 2016.

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